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Blood Pressure Response to Treadmill Stress Testing-Interpretation and Critical Appraisal

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Abstract

A progressive and sustained decrease in systolic blood pressure on the continuation of exercise suggests severe left ventricular dysfunction irrespective of the cause. A transient decrease in systolic blood pressure followed by a normal increase in the continuation of exercise does not have any clinical significance. Failure of systolic blood pressure to increase commensurate to an increase in workload suggests the failure of adequate increase in left ventricular stroke volume with increasing workload. At present there is no consensus about the definition and significance of the exaggerated increase in systolic blood pressure during exercise. This is because different authors have used different criteria for defining abnormal response. An increase in diastolic blood pressure by 10 mm Hg over resting diastolic blood pressure or peak diastolic blood pressure of 110 mm Hg is significant and may be associated with a future risk of hypertension at rest. There is no consensus about the magnitude of the fall in systolic blood pressure during the initial few minutes of recovery. A paradoxical increase rather than a decrease in systolic blood pressure during recovery may be associated with coronary artery disease. Correct auscultatory measurement of blood pressure at peak exercise is difficult. Therefore, some authorities recommend the evaluation of blood pressure at a submaximal workload. This area needs further evaluation.

Keywords: Bruce Protocol; Coronary Artery Disease; Cardiovascular Accident; Diastolic Blood Pressure; Exercise Stress Test; Systolic Blood Pressure; Stroke; Treadmill Test

Introduction

The blood pressure response is measured and entered routinely in the report of every treadmill test. The definition and clinical significance of 'normal' and 'abnormal' blood pressure responses are, however, not widely appreciated. This is because different authors have used different criteria to define abnormal response. Further authors of various review articles have not critically analysed the original studies. Clinicians mostly concentrate on electrocardiographic changes. Blood pressure changes usually remain ignored. We have tried to critically review the available literature and draw some impressions that can be useful for clinicians. An understanding of the normal hemodynamic changes during dynamic exercise is needed to understand the etiology and significance of various abnormal responses.

Normal Hemodynamic Changes during Dynamic Exercise that Control Blood Pressure

Systolic Blood Pressure

During Exercise: Systolic blood pressure is dependent on left ventricular stroke volume and stiffness of the arterial system. Left ventricular stroke volume depends on left ventricular preload (right ventricular stroke volume) and contractility of the left ventricular myocardium. Left ventricular myocardial

contractility depends on preload, left ventricular systolic function and sympathetic drive. Normally, during dynamic exercise systemic venous return increases due to contraction of the exercising muscles [1]. Simultaneously, there is an increase in the sympathetic drive with the result that systolic blood pressure rises progressively with increasing workload. An increase in stroke volume and systolic blood pressure is maximum in the beginning of the exercise. Left ventricular stroke volume does not increase linearly with increasing exercise as there is an upper limit to the increase in left ventricular filling and contractility [2]. Therefore, increase in systolic blood pressure with increasing workload is not linear. Gradually it reaches a plateau. The subsequent increase in systolic blood pressure is mainly because of an increase in the heart rate [3].

There might be a slight decrease (usually less than 10 mm Hg) if the patient reaches his limit of exhaustion. The exact mechanism of this decrease at peak exercise is not known. The sudden increase in vagal tone or decrease in vascular resistance could be responsible. Lactic acid accumulation and metabolic acidosis secondary to prolonged anaerobic exercise could also be responsible [4]. In some patients a vasovagal response could be responsible. It is important to remember that vasovagal response is associated with bradycardia as opposed to other causes of hypotension which are always associated with tachycardia. Thus major hemodynamic factors controlling exercise-induced increase in systolic blood pressure include cardiac performance (governed by the level of sympathetic activity and underlying myocardial or coronary artery disease), characteristics of major arteries (influenced by arterial compliance and influence of reflected waves) [5], and peripheral factors (including peripheral vascular resistance and properties of the venous circulation) [6].

Exercise-induced increase in systolic blood pressure is also affected by resting systolic blood pressure, age, sex, body mass index , physical conditioning of the patient and current use of cardiovascular drugs [7-12]. Resting systolic blood pressure is a major determinant of the peak systolic blood pressure response to exercise [13,14]. Maximal systolic pressure increases with advancing age. This could be due to increasing stiffness of the systemic arteries with advancing age. The increase is less in females as compared to males of similar age. Lower muscle mass, lower physical fitness and lower maximum exercise capacity of females could be contributory. Physically conditioned subjects can attain greater maximum systolic blood pressure as they can exercise for longer periods. Persons with high body mass index have higher systolic blood pressure responses. Children and adolescents with the presence of cardiovascular risk factors have higher systolic blood pressure responses during exercise [15,16]. Treadmill testing is a weight-dependent exercise. Therefore, systolic blood pressure response is greater during treadmill testing as compared to bicycle ergometry. All these variables should be considered while interpreting the clinical significance of systolic blood pressure response to exercise in an individual.

During recovery: During recovery, parasympathetic drive increases and sympathetic tone decreases. Simultaneously there is a decrease in venous return due to the cessation of contraction of the exercising muscles. Therefore, stroke volume declines with the resultant decrease in systolic blood pressure. By the end of the third minute of recovery, systolic blood pressure may fall below the resting systolic blood pressure [3]. This happens because vasodilation in the exercising muscles persists for some time even after cessation of exercise.

Diastolic Blood Pressure

Diastolic blood pressure depends on total peripheral vascular resistance. During exercise, there is dilatation of arteries of the exercising muscles in response to increased demand of oxygen and nutrients and to remove the end product metabolism by the exercising muscles. This is accompanied by vasoconstriction in non-exercising skeletal muscles and splanchnic circulation with the result that there is no or minimal change in the total systemic vascular resistance. Diastolic blood pressure, therefore, shows no or minimal change (+ 10 mm Hg) during exercise [14,17].

The dilatory capacity of peripheral arteries is influenced by autonomic nervous control [18]. Subclinical atherosclerosis, endothelial dysfunction and abnormalities of smooth muscles can also affect the dilatation of vessels in exercising muscles. These variations can explain interindividual variability in diastolic blood pressure response to dynamic exercise.

Difficulties in Accurate Measurement of Blood Pressure during Treadmill Testing

There are some inherent difficulties in correct auscultatory measurement of blood pressure [19]. Some well-defined procedure has to be followed4 e.g. correct cuff size, correct rate of deflation of the cuff, correct detection of the first phase and differentiation of phase four and phase five of Korotkoff sounds, recording of phase four sound if Korotkoff sounds are audible up to zero, recording blood pressure before stopping exercise to get peak blood pressure, and identifying auscultatory gap. Most of the laboratories use a standard caff for all patients [19,20]. Correct detection of diastolic blood pressure during exercise is also difficult due to difficulties in correct detection of Korotkoff sounds during exercise [21]. It needs proper training and experience. These

days treadmill testing is performed by technicians who are usually not thoroughly trained in the correct auscultatory measurement of blood pressure.

Correct auscultatory measurement of systolic blood pressure is difficult during the third stage and onwards due to the noise of the treadmill, sounds produced by striking of patient's feet on the belt of the treadmill, the tendency of the patient to flex the elbow, contraction of the upper limb muscles to firmly grip the front handrail and body movements [19,22]. Isometric exercise of the upper limb in an attempt to firmly hold the front handrail adds to the increase in systolic blood pressure [19].

Automatic blood pressure measuring devices use a microphone on the brachial artery and gating of sounds with the R waves of the ECG. This helps in the exclusion of extraneous sounds occurring during diastole [4]. It is, however, important that measurement is made during the last 45 seconds of each stage so that correct maximum blood pressure at the end of each stage is entered into the computer. Most of the time measurement of the blood pressure is completed after the onset of the next stage. This results in the wrong recording. Automatic measurement is not useful in irregularly occurring R waves (arrhythmias) [4]. Voluntary flexion of the elbow to firmly hold the front handrail can add extraneous sounds. Diastolic blood pressure depends on total peripheral vascular resistance.

Normal Blood Pressure Changes during Exercise & Recovery

There is no literature on blood pressure changes in absolutely normal persons without any cardiovascular risk factors or family history of hypertension [23]. Prehypertensives cannot be considered 'normal' as they have an abnormal increase in blood pressure during exercise. Some information is available from studies on the general population. There is no consensus on the maximum systolic blood pressure during exercise [23]. Sharman JE, et al. [19] observed an increase of 10.2 mm Hg/MET in systolic blood pressure. They observed that this increase could plateau at peak exercise. Sieira MC, et al. [20] observed an increase of 7 to 10 mm Hg/MET. Daida H, et al. [7] studied 'apparently healthy' individuals. They observed that systolic blood pressure increases by 50 to 60 mm Hg in men and 40 to 50 mm Hg in women from rest to peak exercise. There was a tendency towards a lower range in persons older than 70 years. They observed that maximal systolic blood pressure was less than 210 mm Hg in males and 190 mm Hg in females. The increase was greater in persons above 40 years. Surawicz B, et al. [18] have mentioned a wider range (160 to 220 mm Hg) for systolic blood pressure with maximal effort. Criqui MH, et al. [24] have observed that systolic blood pressure increases by about 30 mm Hg in males and by about 28 mm Hg in females by the end of the third minute of exercise. Laukkanen JA, et al. [13] observed that systolic blood pressure usually increases by 50 to 70 mm Hg.

The systolic blood pressure shows a mild decrease immediately after exercise and rises temporarily again after one minute. This transient fall in systolic blood pressure is due to vasodilation persisting in exercise muscles as a result of the accumulation of lactic acid at peak exercise in the face of a reduction of stroke volume due to a sudden reduction in venous return [25,26].

Diastolic blood pressure decreases slightly or shows no change with exercise [17,24], due to a lack of any significant change in total peripheral vascular resistance.

Abnormal Blood Pressure Responses to Dynamic Exercise and Their Significance

There is no literature on blood pressure response to dynamic exercise in absolutely normal individuals without cardiovascular risk factors and a family history of hypertension. No cut points are, therefore, available which can be used in a given patient to correctly define an abnormal response. Most of the workers have used arbitrary values in their studies.

Abnormal Systolic Blood Pressure Response

The literature on this topic can be discussed under the following heads:

- Sustained decrease in systolic blood pressure (Hypotensive response).
- Decrease in systolic blood pressure followed by the increase on continued exercise.
- Failure of adequate increase in systolic blood pressure.
- Initial increase followed by a decrease in blood pressure.
- Decrease in systolic blood pressure at peak exercise.
- Exaggerated fall in systolic blood pressure soon after exercise.
- Abnormal increase in systolic blood pressure during exercise (Hypertensive response).
- Abnormal blood pressure response during recovery.

Sustained decrease in systolic blood pressure below pre-exercise standing systolic blood pressure

There is no consensus regarding the magnitude of fall in systolic blood pressure that should be considered abnormal. Most of the workers have considered a fall below pre-exercise standing systolic blood pressure as abnormal [17,27-29]. Others have defined a fall of 10 mm Hg or more as significant [30,31].

A hypotensive response should be considered 'true' only it there is a sustained and progressive decrease in systolic blood pressure on the continuation of exercise. Such a response is due to vasodilatation in the exercising muscles and /or neurocardiognically mediated vasodilatation without a simultaneous increase in left ventricular stroke volume [32]. It suggests severe left ventricular dysfunction from any cause. It can occur in severe dilated cardiomyopathy or severe coronary artery disease. When it is secondary to severe coronary artery disease, patients always have angina and/or significant ST-segment changes [4,29,32,33]. Such a response strongly suggests severe left main or triple vessel disease [34]. It is, however, very important to remember that the absence of such a response does not exclude severe coronary artery disease. On the contrary, most of the patients with severe left main or triple vessel disease do not have a hypotensive response.

Earlier during exercise hypotensive response occurs, more severe is the coronary artery disease. Successful bypass surgery has been shown to reverse hypotensive response [30]. Hypotensive response is associated with a poor prognosis due to underlying severe coronary artery disease and/or severe left ventricular systolic dysfunction.

A fall in systolic blood pressure below pre-exercise blood pressure is the strongest predictor of cardiovascular death [31,35,36]. Some workers feel that a hypotensive response can be a predictor of the future occurrence of atrial fibrillation [37]. This is understandable if the patient has left ventricular failure with secondary left atrial enlargement. Patients with hypotensive response also have a relatively greater risk of developing VT or VF [38]. This is probably related to underlying severe coronary artery disease.

Transient decrease in systolic blood pressure followed by increase on continued exercise

Some persons who have anxiety about the test can develop some increase in systolic blood pressure before exercise. After starting exercise, their anxiety may be relieved and their systolic blood pressure may return to their normal level. In these cases, there are no symptoms or electrocardiographic changes. Systolic blood pressure starts rising on the continuation of exercise. Such a response does not have any adverse prognostic significance. Therefore, such a response should not be considered a true hypotensive response [39,40].

The development of an arrhythmia can also cause a fall in systolic blood pressure [39]. Blood pressure may start rising again if the arrhythmia reverts spontaneously. It does not suggest poor prognosis similar to patients with underlying severe coronary artery disease or severe left ventricular dysfunction.

Failure of adequate increase in systolic blood pressure with increasing workload

Normally, the systolic blood pressure increases progressively with increasing workload. If the systolic blood pressure does not increase commensurate with increasing workload, it is considered 'inadequate.' It is difficult to correctly define the inadequacy of increase for a given patient because there is no data about the magnitude of increase in systolic blood pressure at different workloads in normal individuals without cardiovascular risk factors and family history of hypertension. Most of the authors have used arbitrary values to define an inadequate increase in systolic blood pressure. Various criteria used by different authors are:

- Failure of systolic blood pressure to increase by 10 mm Hg or more after the first minute of exercise [19,33].
- Increase in systolic blood pressure by less than 44 mm Hg in men with an average age of 53 + 12 years [40,41].
- Maximum systolic blood pressure of 140 mm Hg or less [38,42].
- Rise of systolic blood pressure to less than 140 mm Hg or a rise of less than 10 mm Hg over pre-exercise value in spite of normal effort [39]. 'Normal' effort has not been defined.
- Increase of less than 20 mm Hg during the entire effort [20].
- Maximum systolic blood pressure less than 140 mm Hg [20].
- Increase of less than 40 mm Hg over resting systolic blood pressure [20].

One limitation of the criteria of maximum systolic blood pressure is that it does not take into consideration the resting systolic blood pressure of the patient which is an important determinant of maximum systolic blood pressure [6,13,14]. Another thing that has not been clarified in the above studies is whether the exercise was symptom-limited or terminated at age-predicted maximal heart rate. Development of angina or left ventricular systolic dysfunction can also reduce increase in systolic blood pressure. Further, these criteria do not include workload-dependent increase in systolic blood pressure and actual duration of exercise. We feel that the observation of Sharman, et. al (a normal increase of 10.2 mm Hg/MET) [19], can be used to define the adequacy of exercise induced increase in systolic blood pressure till more data is available regarding workload-dependent increase in systolic blood pressure in absolutely normal persons without cardiovascular risk factors and any family history of hypertension.

Failure of adequate increase in systolic blood pressure is due to failure of progressive increase in stroke volume with increasing workload despite decreasing systemic vascular resistance due to dilatation of arteries in the exercising

muscles. It could be because of left ventricular systolic dysfunction from any cause including severe coronary artery disease. When such a response is due to severe coronary artery disease, patients almost always develop angina and/or significant ST-segment changes. Significant mitral or aortic valve stenosis can also prevent the progressive increase in stroke volume [43]. These conditions are, however, excluded during clinical examination and echocardiography performed routinely before taking patients for treadmill stress testing. Aortic regurgitation and mitral regurgitation do not pose a problem because they do not restrict stroke volume with increasing exercise. Hypovolemia and the use of antihypertensive medicines can also cause such a response [39]. Hypertrophic cardiomyopathy with significant left ventricular outflow obstruction, pulmonary vascular disease and central venous obstruction are uncommon causes for such a response [19]. Abnormal sympathetic control with abnormal vasodilation in exercising as well as non-exercising muscles can also produce an inadequate increase in systolic blood pressure.

In patients with clinically indicated stress testing, failure of adequate increase in systolic blood pressure is associated with increased incidence of cardiovascular events and all-cause mortality [44]. In a patients who has sustained myocardial infarction, an inadequate increase in systolic blood pressure suggests significant left ventricular dysfunction and/or persistent significant coronary artery disease [25].

Initial increase followed by a decrease in systolic blood pressure

It has been defined as a fall of 20 mm Hg or more from peak systolic blood pressure [33,36,39,45,46]. However, the peak systolic blood pressure, duration of exercise and workload has not been defined in these studies. Irving JB, et al. [38] have defined it as a decrease of 10 mm Hg after the initial increase. Once again the magnitude of the initial increase, duration of exercise and workload has not been defined.

Such a response can be seen in left main and/or triple vessel disease [33]. In such a situation it is usually associated with angina and/or significant ST-segment changes. It can also occur in late-onset orthostatic hypotension. Significant fall in systolic blood pressure after peak exercise can occur in otherwise healthy individuals due to a sudden reduction in venous return from the exercising muscles or a sudden increase in vagal tone. In the absence of angina and/or significant ST-segment changes, such a response has little predictive value [46].

Fall in systolic blood pressure at peak exercise

Some normal persons can have mild fall in systolic blood pressure when they are exhausted [26]. It can be due to vasovagal reaction. Such a response is associated with bradycardia. Anaerobic metabolism and collection of lactic acid in the exercising muscles Ellestad MH, et al. [26] can also cause increased dilatation of arteries in exercising muscles. This factor may be important in other cases. These conditions produce sinus tachycardia. Such a hypotensive response has no diagnostic or prognostic significance.

Exaggerated fall in systolic blood pressure soon after exercise

Mild fall in systolic blood pressure is a normal phenomenon. It is due to the sudden reduction in venous return from exercising muscles, fall in sympathetic tone and increase in vagal tone. In some patients, regression of vasodilatation in the exercising muscles may be relatively slow [46]. Sudden reduction in venous return results in a reduction in stroke volume in the face of persisting vasodilatation in the exercising muscles. This results in an exaggerated fall in systolic blood pressure. This may result in a feeling of giddiness or blackout and may need the support of the supervising staff. Further reduction in systolic blood pressure is relatively slow as the tone of arteries in exercising muscles returns to normal. Such a response does not have any diagnostic or prognostic significance.

Hypertensive response (Abnormal increase in blood pressure)

- **Abnormal increase in systolic blood pressure:** At present, there is no consensus regarding definition [20,23,46,47], of exaggerated systolic blood pressure during treadmill testing. It is for several reasons. Systolic blood pressure during treadmill testing depends on several confounding factors e.g. resting systolic blood pressure [6,13], age [7,8], sex [7,9], body mass index [10], physical conditioning [11], presence of cardiovascular risk factors,15,16 family history of hypertension and current use of antihypertensive drugs [4,12]. There is no study that has evaluated a stagewise increase in systolic blood pressure in 'absolutely normal' individuals without confounding factors [46]. Therefore, there are no cut-off values to correctly define abnormal increases in systolic blood pressure during different stages of treadmill testing. Most of the authors have used arbitrary values that are not corrected for various confounding factors [46-49]. Some authors have proposed absolute values to define exaggerated systolic blood pressure. Proposed values have a wide range (190 mm Hg to 230 mm Hg) [13,50-53]. Ren JF, et al. [48] have suggested a value of more than 190 mm Hg for patients with hypertension. However, a given value does not have the same clinical significance in different persons with different combinations of confounding factors [7]. Filipovsky J, et al. [49] adjusted exercise systolic blood pressure for

resting systolic blood pressure. Exercise systolic blood pressure that was initially considered exaggerated became insignificant after adjustment with resting systolic blood pressure. Other workers have defined exaggerated systolic blood pressure by the magnitude of increase in systolic blood pressure per minute of exercise. Once again the suggested values have a wide range (9.4 mm Hg/ minute to 19.7 mm Hg/minute) [13,52,54]. Some authors have used a value exceeding the 95th percentile of the studied population [14,55]. This criterion cannot be used for an individual undergoing treadmill test unless the particular laboratory has a normogram for the local population with a risk profile similar to that of the patient under evaluation. This looks practically impossible. Kim D, et al. [47] have used the criterion of the magnitude of increase in systolic blood pressure during exercise over the resting pre-exercise systolic blood pressure (more than 60 mm Hg in men and more than 50 mm Hg in women). These criteria cannot be applied to an individual patient because several factors other than gender affect the response of exercise in a given individual [23].

At present it is felt that confounding factors, clinical profile and various exercise electrocardiographic findings should be considered before interpreting the clinical significance of a particular exercise blood pressure in a given patient.

- **Abnormal increase in diastolic blood pressure:** Different authors have proposed different criteria. Lauer MS, et al. [51] have suggested a value of more than 110 mm Hg. Sieira MC, et al. [20] have proposed an increase of more than 10 mm Hg over pre-exercise diastolic pressure. Singh JP, et al. [14] have considered a value more than the 95th percentile of sex-specific, age-adjusted value during the second stage of the treadmill test as abnormal. Athletes reach a relatively lower peak diastolic blood pressure [20]. There is no study of change in diastolic blood pressure during different stages of treadmill testing is 'normal' persons. Correct measurement of diastolic blood pressure needs good training and experience in detecting the fifth phase of Korokoff sound [21]. This results in significant interindividual variability in values. At times Korokoff sounds may be audible up to zero level during exercise. Resting diastolic blood pressure is the main determinant of diastolic blood pressure during exercise [24].

At present it is felt that normally diastolic blood pressure does not change or shows a mild decrease during exercise [14,17]. Any magnitude of the definite increase is, therefore, abnormal. An increase of more than 10 mm Hg should be considered important. A value of more than 110 mm Hg increases specificity but decreases sensitivity.

- **Pathophysiology of hypertensive response**

Systolic hypertensive response: During exercise, stroke volume cannot increase beyond a point. Exaggerated systolic blood pressure during exercise is, therefore, due to the failure of adequate dilatation of peripheral vasculature [13,18]. Several factors are considered to contribute to impaired vasodilatation. These include:

- Excessive stimulation of the sympathetic nervous system [18,46,47].
- Decreased aortic distensibility. Aortic stiffness increases with aging and atherosclerosis [5,56]
- Impaired endothelium-dependent vasodilatation [57,58].
- Augmented rise in angiotensin II [53,59].
- Diminished nitric oxide and prostaglandin bioavailability [60].
- Cardiovascular risk factors [15,16].
- Inflammation.61 Site and nature of inflammation is not established. The mechanism of exaggeration of exercise-induced hypertension in such cases is not clear.

At present it is felt that cardiovascular risk factors are important in children and adolescents [15]. Impairment of endothelial function is usually important in younger individuals [47]. Arterial stiffness is usually important in the elderly [47]. Inflammation is contributory in patients with chronic inflammatory diseases. More than one factor could be contributory in a given case. Persons with normal resting systolic blood pressure and exaggerated systolic blood pressure response during exercise probably have the preclinical stage of hypertension with subtle pathophysiologic abnormalities like increased peripheral vascular resistance [61].

Diastolic hypertensice response: Increased resting peripheral vascular resistance and impaired capacity for exercise-induced vasodilatation are considered responsible for the diastolic hypertensive response [62].

- **At what level of exercise should the blood pressure be evaluated**

At submaximal exercise or at maximal exercise?: Most of the studies have evaluated systolic blood pressure at peak exercise. Some workers have, however, evaluated blood pressure response at the submaximal level of exercise.

Lim PO, et al. [63] observed that moderate but not maximal intensity systolic blood pressure better correlated with left ventricular mass in hypertensives. Erikssen G, et al. [64] evaluated 'healthy' men aged 40 years to 60 years. They used bicycle ergometry. All individuals were followed for 26 years. An increase in systolic blood pressure at submaximal workload, exercise capacity, and depression of

the ST-segment correlated with a significant risk of major cardiovascular events. Peak exercise systolic blood pressure did not correlate with the incidence of cardiovascular events. Kokkinas P, et al. [65] evaluated the association of exercise capacity and increase in systolic blood pressure at moderate intensity treadmill exercise with left ventricular mass in prehypertensive individuals. Hypertensive response (> 150 mm Hg) at moderate intensity treadmill exercise (Bruce protocol stage 2, 5 METs) correlated with ventricular mass.

Kuri S, et al. [54] have observed that 1SD increment in systolic blood pressure at 2 to 4 minutes from the start of exercise correlated with an increased future risk of stroke. Maximum systolic blood pressure was not associated with the future risk of stroke.

Schultz MG, et al. [66] performed a metaanalysis of exercise-induced hypertension, cardiovascular events and mortality in patients undergoing exercise stress testing. They observed that a hypertensive response at a moderate workload better correlated with the future occurrence of cardiovascular events after adjustment for other cardiovascular risk factors, than systolic blood pressure at a high workload.

Evaluation of an increase in systolic blood pressure at submaximal exercise has several advantages over evaluation of systolic blood pressure response at a high workload [15]. Systolic blood pressure is more easily and accurately measured during the second stage of exercise because it is not influenced by exercise duration, physical conditioning and patient cooperation [15,47,67,68]. Le VV, et al. [46] have also suggested that exercise induced hypertension must be diagnosed if it is observed at mild to moderate levels of exercise. Correct measurement is usually difficult at very high levels of exercise. Schultz MG, et al. [69] have shown that systolic blood pressure measured during mild to moderate exercise strongly predicts 'masked hypertension' in persons with hypertensive response. Schultz MG, et al. [66] felt that systolic blood pressure at submaximal workload better correlates with variations in blood pressure during day-to-day life. Sharman JE, et al. [19] have suggested that an exaggerated increase in systolic blood pressure at low workload (less increase in cardiac output) could be suggestive of impaired vasodilatation. It could be suggestive of impaired vasodilatation. It could suggest abnormal regulation of blood pressure [23].

At present it is felt that measurement of an increase in systolic blood pressure by the end of the second stage of the Bruce protocol allows more correct and reproducible results than measurement at peak exercise. It more closely correlates with the pathophysiology of hypertensive response during exercise. Criqui MH, et al. [24] have suggested that a normal increase in systolic blood pressure by the end of the first stage of Bruce protocol (3 minutes of exercise) is around 30 mm Hg in men and around 28 mm Hg in women. However, there is a lack of adequate data about normal increases in blood pressure at different durations of exercise (METs) in normal persons and persons with various confounding factors. It is very necessary to correctly define an abnormal increase in blood pressure at 'submaximal exercise' in a given individual. More work is needed to correctly defined hypertensive response at different levels of 'submaximal' workload [69].

- **Prognostic implication**

Of systolic hypertensive response

Increased risk of resting hypertension in future: Several workers have proposed that systolic hypertensive response during exercise was associated with increased risk of resting hypertension in future [52,70-76].

However, these studies have several limitations. These studies have enrolled either only males or small number of females [52]. Different cut off values have been used to define exaggerated blood pressure response. Manolio TA, et al. [71] used cut point of > 210 mm Hg in males and > 190 mm Hg in females. Allison TG, et al. [52] used cut point of > 214 mm Hg. Miyai N, et al. [75] used the criteria of increase in systolic blood pressure by more than 33 to 59 mm Hg over resting blood pressure. The population studied by different workers was also significantly different. Manolio TA, et al. [71] studied 'normotensive volunteers' with mean age of 25 years. Allison, et al. [52] studied 'asymptomatic normotnesive' subjects with mean age of 50+10 years. Franz IW [76] and Laukkanen JA, et al. [13] studied only males with mean age of 42+6 years and 52+5 years respectively. These persons had greater likelihood of developing hypertension over the long period of follow-up because of their age at the time of enrolment irrespective of their systolic blood pressure during exercise. Miyai N, et al. [78] studied individuals with 'high normal' blood pressure. Wilson MF, et al. [77] studied individuals with 'high normal' blood pressure and family history of hypertension. These persons were genetically predisposed to develop hypertension with passage of time irrespective of their systolic blood pressure response during exercise.

Most of the studies have not performed multivariate analysis to find independent significance of systolic blood pressure response during exercise. Studies that have tried to evaluate association with other variables have not found exercise systolic blood pressure to be significant. In the study of Manolio TA, et al. [71] persons with exaggerated systolic blood pressure at the beginning of the study had an increase of 5 mm Hg in resting systolic blood pressure and 1 mm Hg in diastolic blood pressure after five years. After adjusting for confounding factors, there was an increase of only 2 mm Hg

in the resting systolic blood pressure. Such a minimal change could be due to natural increase in blood pressure over years or even an interobserver difference in measurement. Authors also concluded that there was stronger association between resting blood pressure and risk for subsequent hypertension than with exercise systolic blood pressure.

Singh JP, et al. [14] have also observed that after adjusting for confounding factors, peak exercise systolic blood pressure did not predict future hypertension. Baseline resting systolic and diastolic blood pressures had stronger association with new onset hypertension. Filipovsky J, et al. [49] also observed that exaggerated blood pressure to exercise became insignificant after adjusting to resting blood pressure.

These observations reflect that individuals with exaggerated systolic blood pressure during exercise have pathophysiological changes in the preclinical stage which gradually lead to the development of hypertension at rest [16,49,77,79].

At present it is felt that there is no convincing evidence of any correlation between peak exercise systolic blood pressure and future development of hypertension at rest. Those who develop hypertension at rest in future most likely have pathophysiological changes in the preclinical stage of hypertension at the time of treadmill test.

Left ventricular hypertrophy: Some authors have reported association of greater left ventricular mass in persons with exaggerated systolic blood pressure during exercise. Ren JF, et al. [48] observed that individuals with exercise systolic blood pressure of 190 mm Hg or more had greater left ventricular mass as compared to individuals with exercise systolic blood pressure less than 190 mm Hg. However, their patients had resting hypertension which could have contributed to left ventricular hypertrophy. Further, they did not exclude the effect of other confounding factors. Gottadiener JS, et al. [55] evaluated men who had normal blood pressure at the time of enrolment. They observed that men with maximal exercise systolic blood pressure of 210 mm Hg or more had left ventricular hypertrophy. These authors enrolled only men and did not exclude the effect of other confounding factors. Sung J, et al. [80] also observed that exercise blood pressure response was related to left ventricular mass. They also did not adjust their data for other variables.

Lim PO, et al. [63] compared office, ambulatory and exercise blood pressure to find determinants of left ventricular wall thickness mass index in hypertensive patients. They concluded that increase in systolic blood pressure at moderate work load correlated with left ventricular mass. Maximal systolic blood pressure did not correlate with left ventricular mass. However, their patients had resting hypertension. Further, they also did not adjust their data for other confounding variable. Sharman JE, et al. [81] observed that in patients with hypertensive response to exercise, 'masked hypertension' was associated with left ventricular remodelling.

There could be some possibilities for the contradictory observations of different workers. Firstly, the magnitude of left ventricular hypertrophy to a given afterload is also influenced by genetic predisposition for left ventricular hypertrophy. Persons susceptible to left ventricular hypertrophy could be simultaneously prone to exaggerated systolic blood pressure response to exercise. Secondly, some persons with exaggerated blood pressure response to exercise have a tendency towards abnormal increase in blood pressure during stresses of day to day life (masked hypertension). In such persons, hypertensive blood pressure response during treadmill testing could correlate with changes in systolic blood pressure during stress conditions of daily life [82]. This could result in left ventricular hypertrophy. Thirdly, hypertensive response to exercise may not be accompanied by elevation of central blood pressure in all persons. Elevation of central blood pressure is an important factor that controls the effect of hypertension on the left ventricle [83].

At present it is felt that there is no consensus about correlation between exercises induced increase in systolic blood pressure and left ventricular hypertrophy. Left ventricular hypertrophy is influenced by increase in blood pressure during stresses of day to day life, genetic predisposition to left ventricular hypertrophy, central hemodynamics and resting blood pressure. Correct evaluation of etiological correlation between systolic hypertensive response during treadmill testing and left ventricular hypertrophy needs long term studies of normotensive persons with periodic ambulatory blood pressure monitoring, evaluation of central hemodynamics during exercise and multivariate analysis to exclude the effect of various confounding factors.

Left ventricular diastolic dysfunction: There is no consensus regarding the presence of left ventricular diastolic dysfunction in patients with systolic hypertensive response to exercise. Tokamura T, et al. [84] observed impaired left ventricular diastolic function in patients with a systolic hypertensive response to exercise. Tsiofis C, et al. [85] also observed that exaggerated exercise systolic blood pressure response is related to left ventricular diastolic dysfunction as assessed by tissue Doppler imaging.

On the other hand, Mottram PM, et al. [86] observed that systolic hypertensive response to exercise was associated

with impaired left ventricular systolic function without diastolic dysfunction or left ventricular hypertrophy.

At present it is felt that left ventricular diastolic dysfunction is also dependent on various factors causing left ventricular hypertrophy. Therefore all persons with exaggerated systolic blood pressure response to exercise need not have left ventricular diastolic dysfunction.

Risk of future occurrence of cardiovascular events: There is no consensus about the correlation of systolic hypertensive response during a treadmill test and the risk of future occurrence of cardiovascular events. Weiss SA, et al. [87] studied exercise blood pressure response and future incidence of cardiovascular death in asymptomatic individuals. They observed that peak systolic blood pressure of more than 210 mm Hg in men and 190 mm Hg in women may be indicative of the risk of future development of resting hypertension or adverse cardiac events. The authors, however, did not adjust their data for the presence of other cardiovascular risk factors at the time of enrolment and during long-term follow-up. Also, there is no information as to how many individuals had clinical and/or electrocardiographic evidence of myocardial ischemia during the index treadmill test. It is also not clear what was the incidence of the future cardiovascular accident in persons with the systolic hypertensive response but without other cardiovascular risk factors and without any evidence of myocardial ischemia in the index treadmill test.

Erikssen G, et al. [64] evaluated healthy men aged forty to sixty years by bicycle ergometry. On a follow-up of 26 years, ST-segment response, elevated systolic blood pressure above normal at submaximal workload and exercise capacity were independent predictors of significant risk for major cardiovascular events. It is not clear how many persons with elevated systolic blood pressure at submaximal exercise also had abnormal ST-segment response. It is also not clear how many persons without ST-segment abnormality had abnormally high systolic blood pressure and what was their prognosis. Individuals were already 40 to 60 years old at the time of entry into the study. On a follow-up over 26 years (final age 66 to 86 years), most of the persons were already at high risk for cardiovascular events. The authors have also not adjusted their observations for the presence and severity of other cardiovascular risk factors at entry and during the period of long follow-up. Further, as discussed earlier, 'submaximal' exercise needs to be defined before it can be applied to an individual performing a treadmill test.

Several other workers have observed that exaggerated systolic blood pressure during exercise did not correlate with the incidence of cardiovascular events during follow-up specially after adjusting for resting systolic blood pressure [52,88].

On the other hand, several studies have observed that hypertensive response is associated with lower incidence and severity of coronary artery disease lower incidence of cardiovascular accidents and overall mortality [89-92]. It is understandable because exercise-induced increase in systolic blood pressure is dependent on left ventricular function. Hypertensive response, therefore, indirectly suggests the good capacity of the left ventricle to progressively increase cardiac output with increasing exercise [13].

Hedberg P, et al. [93] observed that an increase of more than 55 mm Hg in systolic blood pressure was associated with decreased risk of overall mortality as compared to persons with systolic blood pressure increase of less than 33 mm Hg. Gupta MP, et al. [41] observed that an increase of more than 44 mm Hg in systolic blood pressure during exercise was associated with improved survival. Laukkanen JA, et al. [13] observed that middle-aged men with an increase of 36 to 63 mm Hg in systolic blood pressure during exercise had a lower rate of myocardial infarction as compared to individuals with a higher increase in systolic blood pressure. Authors have, however, not adjusted their data for various cardiovascular risk factors at enrolment and any change during follow-up. Data has also not been adjusted with clinical and electrocardiographic findings suggestive of myocardial ischemia during the index treadmill test. All these authors have observed different cut-off values. No common value can be derived that can be applied to a given individual.

At present it is felt that there is no convincing evidence that exaggerated systolic blood pressure response during treadmill testing alone is related to increased incidence of cardiovascular events in future. Individuals with preclinical hypertension, high normal blood pressure at rest or resting hypertension with other cardiovascular risk factors are more prone to have a hypertensive response during treadmill testing [6,94] and could have a higher risk of cardiovascular events in future. Individuals with unnoticed exaggerated systolic blood pressure response during stresses of day-to-day life could also be susceptible to cardiovascular events in future. Ageing is an important cardiovascular risk factor that has an independent impact on the occurrence of cardiovascular events in long-term follow-up of middle-aged persons. In general, the magnitude of increase in systolic blood pressure with increasing workload suggests good left ventricular function and thus a good prognosis unless there are other significant cardiovascular risk factors. Normally, physically fit individuals have greater maximal increase in systolic blood pressure with increasing workload not only because they can exercise longer but also because they can progressively increase their cardiac output [90].

Future risk of stroke: Kuri S, et al. [54] evaluated 1026 men aged 42-60.4 years by bicycle ergometer. The average follow-up was 10.4 years. They concluded that men with systolic blood pressure rise of more than 19.7 mm Hg per minute of exercise had a greater risk of developing 'any' stroke over an overage follow-up of 10.4 years than men with a rise of less than 16.1 mm Hg per minute during treadmill testing. However, a maximum increase in systolic blood pressure during exercise was not predictive of stroke.

This study has several limitations. Firstly, only men were enrolled. Secondly, the studied population was already at high risk for the occurrence of stroke. The mean age at baseline was 40 to 60.4 years i.e. final age around 50 to 70 years. Body mass index ranged from 18.8 to 40.2 (mean 26.4+3.3). Several persons were smokers. Mean serum LDL was 4.1mmd/L and 3.1 present were diabetic. Resting supine blood pressure ranged from 91 to 206.5 mm Hg. Resting diastolic blood pressure ranged from 65 to 136.7 mm Hg. Thirdly, there is no information regarding the difference in resting blood pressure and other risk factors for stroke in the two groups at the time of enrolment and their progression over the long period of follow-up. Fourthly, the authors did not perform multivariate analysis to exclude the impact of other confounding variables like age, resting blood pressure, body mass index, dyslipidemia, atherosclerosis etc. Fifthly, the authors have not provided any explanation for the lack of any correlation between maximal systolic blood pressure and the risk of future occurrence of 'any' stroke. Sixthly, there is no information about the future incidence of stroke in individuals with a systolic blood pressure rise between 16.1 mm Hg per minute and 19.7 mm Hg per minute. Seventhly, the date has been analyzed for 'ischemia stroke' and 'any stroke'. Causes of 'any stroke' like hemorrhagic stroke or embolic stroke have not been analysed. Eighthly, there is no information about the presence/ absence or severity of atherosclerosis in vessels of the neck and brain at the time of enrolment in the study and their progression over the long period of follow-up. Lastly, the authors have not provided any explanation as to how the rate of rise of systolic blood pressure during an index treadmill test resulted in the occurrence of 'any stroke' after several years. There is no other study supporting the conclusions of these workers.

It is possible that the patients who developed stroke on follow-up had preclinical pathologies which resulted in progressive vascular damage over the years. It is also possible that maximum systolic blood pressure during physical and/ or emotional stresses of day-to-day life was higher in persons who finally developed stroke as a cumulative effect.

At present it is felt that at present there is no convincing evidence to support any association of exaggerated systolic blood pressure during a treadmill test and increased incidence of stroke in future. What is more plausible is that there are some common pathophysiological conditions that are responsible for both hypertensive response during treadmill testing and the occurrence of stroke later in life. More work is needed in this field.

Future risk of albuminuria: Tsioufis C, et al. [96] observed a correlation between exercise blood pressure response, albuminuria and arterial stiffness in hypertensive individuals. The authors did not study normotensive individuals and did not adjust their results with other confounding factors. Resting hypertension perse could result in albuminuria specially if the individuals have other risk factors like diabetes mellitus.

At present it is felt that there is no convincing evidence that hypertensive blood pressure response during treadmill tests has any etiological correlation with albuminuria. There is no properly designed, randomized, control trial in this area.

Overall impression about the prognostic significance of systolic hypertensive response: It is justified to advise lifestyle modification to persons with hypertensive responses. Ambulatory blood pressure monitory is useful. Patients with abnormal hypertensive response to stresses of day-to-day life (masked hypertension) may need additional pharmacotherapy to reduce mean after load. Persons with hypertensive response should also be kept on regular follow-up for early detection of hypertension at rest.

Prognostic significance of exercise-induced increase in diastolic blood pressure: This issue has not been evaluated in detail. Some studies have found the diastolic hypertensive response to be a strong predictor of the future development of resting hypertension [14,71,76]. Also, there is no literature correlating values magnitudes of increase in diastolic blood pressure response with future risk of left ventricular remodelling, cardiovascular events, cerebrovascular accidents and overall long-term prognosis. This area needs further research.

There is no data on the magnitude of the increase in diastolic blood pressure with various levels of exercise in normal persons without any cardiovascular risk factors and a family history of hypertension.

At present it is felt that diastolic hypertension is considered to be due to increased peripheral vascular resistance and impaired capacity for exercise-induced vasodilatation. It is therefore likely that diastolic hypertensive response is more likely to be related to the future risk of hypertension at rest.

Abnormal blood pressure response during recovery

Normally, systolic blood pressure falls rapidly during recovery [17]. It drops by 15% or more within three minutes of recovery6 and this fall may last for several hours [3]. Initial rapid decrease in systolic blood pressure is because of a rapid decrease in heart rate, stroke volume and systemic vascular resistance as a result of a rapid decrease in sympathetic drive and recovery of vagal tone [6]. Systolic blood pressure often drops below pre-exercise level and may remain so for several hours [3]. It is due to persistent vasodilatation in muscles involved in exercise.

Definition of an abnormal response: Failure of adequate fall in systolic blood pressure over the initial few minutes of recovery is considered abnormal. There is no consensus about the definition of abnormal response. Sharman JE, et al. [19] used the ratio of systolic blood pressure at the end of the third minute of recovery upon systolic blood pressure at peak exercise. A ratio of 0.90 or greater was considered abnormal. Abe K, et al. [95] and Tsioufis C, et al. [96] also found this ratio useful in persons with electrocardiographic or echocardiographic left ventricular hypertrophy. Taylor AJ, et al. [97] observed that a ratio of 0.93 correlated with extensive hypoperfusion on quantitative thallium scintigraphy. Mc Ham SA, et al. [98] observed that a three-minute recovery systolic blood pressure to one-minute recovery systolic blood pressure ratio greater than one correlated with angiographic coronary artery disease. Tsuda M, et al. [99] also observed that this ratio was a predictor of cardiovascular mortality. Huang CL, et al. [100] observed that systolic blood pressure was 1.03 times higher at one minute than peak systolic blood pressure and the same as peak systolic blood pressure at three minutes of recovery was suggestive of coronary artery disease in patients with or without hypertension. Kuri S, et al. [54] observed that systolic blood pressure at the end of the second minute of recovery divided by peak systolic blood pressure correlated with future risk of occurrence of stroke. Laukkanen JA, et al. [101] studied systolic blood pressure two minutes after exercise on a cycle ergometer in middle-aged men. They observed that a systolic blood pressure of more than 195 mm Hg, two minutes after exercise correlated with a high risk of myocardial infarction and cardiovascular death. Yosefy C, et al. [102] observed that patients with hypertensive response during exercise (systolic blood pressure more than 180 mm Hg, diastolic blood pressure more than 100 mm Hg) five minutes post-exercise blood pressure of more than 160/90 mm Hg had a higher five-year incidence of coronary artery disease and cardiovascular accidents. Nakashima M, et al. [74] observed that an increase in systolic and diastolic blood pressure immediately after exercise were strong predictors of future hypertension in men [103].

Pathophysiology: The exact mechanism of such an abnormal blood pressure response is not clear. Several explanations are proposed in the literature.

- Abnormality in autonomic function. A slow decrease in sympathetic tone and attenuated increase in vagal activity in the immediate post exercise period [4,104-106].
- Recovery of contractility of the left ventricular myocardium and stroke volume due to relief of ischemia during recovery [17,107,108]. This can be an explanation in patients with exercise-induced significant left ventricular dysfunction.
- Production of catecholamine stimulating metabolites from hypoxic exercising muscles [109]. These catecholamines result in vasoconstriction and reduction in fall in systolic blood pressure during recovery.
- Arteriosclerotic changes and hypertrophy of smooth muscles of vessels can also attenuate a decrease in systolic blood pressure during recovery.
- Decreased nitric oxide synthase activity resulting in impairment of endothetial dependent vasodilatation can also contribute to delayed fall in systolic blood pressure during recovery [110].
- Clinical significance

Detection of coronary artery disease: Patients with coronary artery disease may have a slower rate of decline in systolic blood pressure during recovery as compared to individuals without artery disease [105,111]. However, this finding cannot be used independently for diagnosing or excluding coronary artery disease.

Tsuda M, et al. [99] observed that although patients with coronary artery disease had a slower decline in systolic blood pressure during recovery, symptoms or electrocardiographic changes during recovery were more useful in diagnosing the presence of coronary artery disease. Thomas GS, et al. [4] also observed that there was a significant overlap of values among normal individuals and patients with coronary artery disease. Therefore, recovery ratios do not have any diagnostic significance. Development of angina and/or diagnostic ST-segment changes were more reliable. Thus, it is clear that systolic blood pressure response during recovery is neither sensitive nor specific for diagnosing the presence or absence of coronary artery disease.

Evaluation of the severity of coronary artery disease: Taylor AJ, et al. [97] observed that a peak systolic blood pressure/recovery systolic blood pressure ratio of 0.93 correlated with extensive hypoperfusion on quantitative thallium 201 scintigraphy. The authors, however, did not correlate their observations with the severity of symptoms and electrocardiographic changes. The authors have also not evaluated the sensitivity and specificity of their observation against the findings in coronary angiograms.

Mc ham SA, et al. [98] observed that three minutes to one-minute recovery systolic blood pressure ratio of more than one was associated with a greater likelihood of severe coronary artery disease. However, the sensitivity of this finding for detecting severe coronary artery disease was only 38 percent. The authors also did not correlate the significance of this ratio as compared to symptoms or electrocardiographic findings. It is also not clear if the abnormal recovery systolic blood pressure response gave any add-on information over other clinical or electrocardiographic criteria suggestive of severe coronary artery disease. Further, the ratio could not predict the nature of severity of coronary artery disease (left main disease, 3 vessel disease or 2 vessel disease with involvement of proximal LAD).

Prediction of future risk of acute myocardial infarction: Hashimoto M, et al. [105] evaluated men with a mean age of 59 years with a cycle ergometer. Systolic blood pressure was measured in a sitting position at two minutes in recovery. They observed that individuals with a systolic blood pressure of more than 195 mm Hg, 2 minutes after exercise had a high risk of acute myocardial infarction over a mean follow-up of thirteen years as compared to individuals with systolic blood pressure less than 170 mm Hg. This study has several limitations. Firstly, data from only males were analysed. Secondly, it was a retrospective analysis of the data. Thirdly, systolic blood pressure 2 minutes after exercise was selected for analysis as it was available for all patients. This has introduced a selection bias. Fourthly, at the end of the follow-up period of 13 years, the mean age of patients is expected to be around 66 years. This age per se is a risk factor for myocardial infarction. Fifthly, there is no information about the presence and severity of various cardiovascular risk factors in the two groups of patients in the beginning and any change over the long follow-up period of thirteen years. Sixthly, the final results have not been adjusted for resting blood pressure, peak blood pressure and various cardiovascular risk factors. Seventhly, the incidence of acute myocardial infarction in patients with 2-minute recovery systolic blood pressure between 170 to 195 mm Hg is not clear. Therefore conclusions cannot be applied to an individual with recovery systolic blood pressure in this range. Eighthly, this observation cannot be applied to an individual undergoing an exercise stress test. Finally, individuals with a mean age of 53 years and high 2 minutes recovery systolic blood pressure are very likely to have resting hypertension, the hypertensive response at peak exercise, hypertensive response to stresses of day-to-day life (masked hypertension) and underlying atherosclerosis. The conclusions of the study, therefore, cannot be taken for granted unless the results are adjusted for these important variables.

Prediction of prognosis/ future occurrence of mortality: Yosefy C, et al. [102] studied individuals with a mean age of 60.1+4.1 years. All individuals were followed for five years after an exercise stress test. They observed that five minutes post-exercise blood pressure of more than 160/90 mm Hg was associated with a higher incidence of coronary artery disease and cardiovascular accidents. The sensitivity was however only 50 percent. Further, the data was not adjusted for symptoms and electrocardiographic findings during exercise. Patients who suffered from coronary artery disease or cardiovascular accidents had a higher prevalence of abnormal lipid profile, resting hypertension and other cardiovascular risk factors. Thus, there is no conclusive evidence that delayed recovery of systolic blood pressure after exercise had any independent and significant correlation with the future occurrence of coronary artery disease or cardiovascular accidents. Several other workers have also observed that systolic blood pressure patterns during recovery do not predict prognosis or future risk of mortality [98,41].

Huang CL, et al. [100] have observed that a paradoxical increase rather than a decline in systolic blood pressure after exercise is a predictor of cardiovascular mortality. It is possible. However, the authors have not identified any cut-off value of the magnitude of the paradoxical increase in systolic blood pressure that can be applied to an individual. The sensitivity of these criteria is also expected to be very low. More work is needed to confirm their observations.

Prediction of risk of future development of hypertension at rest: Some workers have observed that a reduced decline in systolic blood pressure during recovery was associated with new onset of hypertension at rest over the next eight to ten years [14,104,113]. In the studies of Tanji JL, et al. [113] and Singh JP, et al. [14], patients were evaluated at submaximal exercise rather than at peak exercise. These workers did not adjust their observations with a family history of hypertension, presence or absence of 'masked hypertension' and presence of risk factors for hypertension at the time of enrolment and subsequently over the long periods of follow-up. It is possible that these individuals had pathophysiological changes seen in the preclinical phase of hypertension which lead to the development of hypertension at rest during the long-term follow-up. The incidence of hypertension in general, increases with advancing age. It is not possible to forecast the risk of future development of hypertension at rest, about an individual, simply by the rate of decline of systolic blood pressure during recovery of one treadmill test.

Risk of future occurrence of stroke: Kuri S, et al. [54] have observed that systolic blood pressure at two minutes during recovery divided by peak systolic blood pressure attained during the exercise test was associated with an increased risk of 'any stroke' and ischemic stroke. The study

has several limitations as discussed before. Also, there is no other study to support the conclusions of this study. Incidence of stroke increase with advancing age even in normal population.

At present it is felt that there is no convincing evidence to forecast the risk of future morbidity in an individual simply by interpreting the decline in systolic blood pressure during recovery of one treadmill test. Total clinical profile, presence of other risk factors and symptoms/ electrocardiographic changes during treadmill test should be considered. Some of these individuals could have 'preclinical' hypertension.

It is justified that individuals with such blood pressure should be evaluated for the presence of 'preclinical hypertension'. Advise regarding lifestyle modification, correction of cardiovascular risk factors and regular follow-up for early detection of hypertension at rest are justified.

Conclusions

- At present, no correct cut-off values are available which can be applied to a given patient to correctly define an abnormal response.
- A progressive decrease in systolic blood pressure (especially below the pre-exercise level) on continuation of exercise is abnormal. Such a response suggests severe left ventricular dysfunction irrespective of the cause.
- A transient decrease in systolic blood pressure followed by an increase on continuation of exercise can be because of anxiety or transient, self-terminated arrhythmia. Such a response does not have any diagnostic or prognostic significance.
- Failure of systolic blood pressure to increase progressively with increasing workload suggests the failure of the left ventricle to increase its stroke volume from any cause
- An initial increase followed by a fall of 20 mm Hg or more can be seen in severe left main and/or triple vessel disease.
- Above mentioned 'hypotensive' responses should be interpreted in the context of the total clinical and electrocardiographic profile of the treadmill test and never in isolation.
- A mild fall in systolic blood pressure can occur at peak exercise or soon after exercise. Such a response does not have any diagnostic or prognostic significance.
- Clinical profile, electrocardiographic findings, the effect of resting blood pressure, age, sex, body mass index, physical conditioning, presence of cardiovascular risk factors and family history of hypertension should be considered before interpreting the clinical significance of a particular peak systolic blood pressure in a given case.
- An increase in diastolic blood pressure by 10 mm Hg over the pre-exercise value or a value of 110 mm Hg or more is significant. Such a response may be associated with a future risk of hypertension at rest.
- There is no consensus about the definition of abnormal systolic blood pressure response during recovery. Failure of a significant decrease over the first three minutes of recovery or a paradoxical increase over peak exercise value is certainly abnormal.
- What is most important is to ensure that blood pressure is correctly measured and timely entered by a competent staff.
- Because of several difficulties in correct measurement at peak exercise, some authorities recommend evaluation of blood pressure at submaximal exercise. More work is needed to correctly define the 'submaximal' workload and the clinical significance of blood pressure readings at such a workload.

References

1. Sonnenblick EH, Braunwald E, Williams ZE, Glick G (1965) Effect of exercise on myocardial force-velocity relation in intact anesthetised man: Relative role of changes in heart rate, sympathetic activity and ventricular dimensions. J Clin Invest 44(12): 2051-2061.

2. Higgnbotham MB, Morris KG, Williams RS, McHale PA, Coleman RE, et al. (1986) Regulation of stroke volume during submaximal and maximal upright exercise in normal man. Circ Res 58(2): 281-291.

3. Fletcher GF, Flipse TR, Safford RE (2017) Exercise in health and cardiovascular disease. In: Fuster V, Harrington RA, et al. (Eds.), Hurst's The Heart. Mc Graw Hill, New York, pp: 2388-2398.

4. Thomas GS, Ellested MH (2018) Blood pressure measurements during exercise testing. In: Thomas GS, Wann LS, et al. (Eds.), Ellestad's Stress Testing. Oxford, New Delhi, pp: 107-134.

5. London GM, Guerin AP (1999) Influence of arterial pulse and reflected waves on blood pressure and cardiac function. Am Heart J 138: 220-224.

6. Jennings GLR (2005) Exercise and hypertension. In: Oparel S, Weber MA (Ed.), Hypertension, Elsevier, Gurgaon, pp: 496-536.

7. Daida H, Allison TG, Squires RW (1996) Peak exercise blood pressure stratified by age and gender in apparently healthy subjects. Mayo Clir Proc 71(5): 445-452.

8. Dimkapa U, Ugwu AC, (2009) Influence of age on blood pressure recovery after maximal effort ergometer

exercise in non-athletic adult males. Eur J Appl Physiol 106(6): 791-797.

9. Dimkapa U, Ugwu AC, Oshi D (2008) Assessment of sex differences in systolic blood pressure responses to exercise in healthy, non-athletic young adults. JEP online 11(2): 18-25.

10. Carletti L, Rodrigues AN, Perez AJ, Vassallo DV (2008) Blood pressure response to physical exertion in adolescents: influence of overweight and obesity. Arq Bras Cardial 91(1): 24-28.

11. Tonaka H, Bassett DR Jr, Tviner MJ (1996) Exaggerated blood pressure response to maximal exercise in endurance-trained individuals. Am J Hypertens 9(11): 1099-1103.

12. Palitini P (1998) Exaggerated blood pressure response to exercise: pathophysiologic mechanism and clinical relevance. J Sports Med Phys Fitness 38(1):1-9.

13. Laukkanen JA, Kuri S (2012) Blood pressure responses during exercise testing - is up best for prognosis?. Annals of Medicine 44(3): 218-224.

14. Singh JP, Larson MG, Monolio TA, O'Donnell CJ, Lauer M, et al. (1999) Blood pressure response during treadmill testing as a risk factor for new-onset hypertension. The Framingham Heart study. Circulation 99(14): 1831-1836.

15. Moller NC, Groenved A, Wedderkopp N, Ried-Larsen M, Kristensen PL, et al. (2010) Cardiovascular disease risk factors and blood pressure response during exercise in healthy children and adolescents. The European Youth Heart Study. J Appl Physiol 109(4): 25-32.

16. Thanassoulis G, Lyass A, Benjamin EJ, Larson MG, Vita JA, et al. (2012) Relation of exercise blood pressure response to cardiovascular risk factors and vascular function in the Framingham Heart Study. Circulation 125(23): 2836-2843.

17. Surawicz B, Tavel M (2008) Stress test. In: Surawicz B, Knilans TK (Ed.), Chou's. Electrocardiography in Clincal Practice. Saunders, Philadelphia, pp: 221-255.

18. Julius S (1994) Abnormalities of autonomic nervous control in human hypertension. Cardiovascular Drugs Ther 8 (1): 11-20.

19. Sharman JE, La Gercha A (2015) Exercise blood pressure: clinical relevance and correct measurement. J Human Hypertens 29(6): 351-358.

20. Sieira MC, Ricort AC, Estrany RS (2010) Blood pressure response to exercise testing. Aputus Med Esport 45: 191-200.

21. White WB, Lund Johansen P, Omvik P (1990) Assessment of four ambulatory blood pressure monitors and measurements of clinicians versus intra-arterial blood pressure at rest and during exercise. Am J Cardiol 65(1): 60-66.

22. Gould BA, Hornung RS, Altman DG, Cashman PM, Raftery EB (1985) Indirect measurement of blood pressure during exercise testing can be misleading. Br Heart J 53(6): 611-615.

23. Tuka V, Rosa Z, Dedinova M, ,et al. (2015) Determinants of blood pressure response to exercise. COR ET VASA 57: 163-167.

24. Criqui MH, Haskell WL, Heiss G Tyroler HA, Green P, et al. (1983) Predictors of systolic blood pressure response to treadmill exercise: the Lipid Research Clinics Program Prevalence Study. Circulation 68(2): 225-233.

25. Engel G, Froelicher F (2008) ECG exercise testing. In: Fuster V, Walsh RA, et al. (Eds.), Hurst's The Heart. Mc Graw Hill, New York, pp: 324-340.

26. Ellestad MH, Thomas GS (2018) The Ellestad Protocol. In: Thomas GS, Wann LS, et al. (Eds.), Ellestad's Stress Testing. Oxford, New Delhi, pp: 149-159.

27. Morris SN. Phillips JF, Jordan JW, McHenry PL (1978) Incidence and significance of the decrease in systolic blood pressure during graded treadmill exercise testing. Am J Cardiol 41(2): 221-226.

28. Ehsani AA, Austin MB, Bietto D (1988) Impaired left ventricular function during exercise in coronary artery disease and exertional hypotension. Cardiology 75(1): 24-31.

29. Fletcher GF, Balady GJ, Amsterdam EA, Chaitman B, Eckel R, et al. (2001) Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. Circulation 104(14): 1694-1740.

30. Weiner DA, Mc Cabe CH, Cutter SS (1982) Decrease in systolic blood pressure during exercise testing: reproducibility, response to coronary bypass surgery and prognostic significance. Am J Cardiol 49(7): 1627-1631.

31. Morris CK, Morrow K, Froelicher VF, Hideg A, Hunter D, et al. (1993) Prediction of cardiovascular death by means of clinical and exercise variables in patients selected for cardiac catheterization. Am Heart J 125(6): 1717-1726.

32. Lele BS, Scalia G, Thomas H, Macfarlane D, Wilkinson D, et al. (1994) Mechanism of exercise hypotension in patients with ischemic heart disease. Role of neurocardiogenically mediated vasodilatation. Circulation 90(6): 2701-2709.

33. Sonmarco ME, Pontius S, Selvester H (1980) Abnormal blood pressure response and marked ischemic ST-segment depression as predictors of severe coronary artery disease. Circulation 61(3): 572-578.

34. Thompson PD, Kelemen MH (1975) Hypotension accompanying the onset of exertional angina: a sign of severe compromise of left ventricular blood supply. Circulation 52(1): 28-32.

35. Dubach P, Froelicher VF, Klein J, Oakes D, Grover-McKay M, et al. (1988) Exercise-induced hypotension in a male population. Criteria, causes and prognosis. Circulation 78(6): 1380-1387.

36. Hamermeister K, Dc Rounen TA, Dodge TA, Zia M (1983) Prognostic and predictive value of exertional hypotension in suspected coronary heart disease. Am J Cardiol 51(8):1261-1266.

37. O Neal WT, Qureshi WT, Blaha MJ, Ehrman JK, Brawner CA, et al. (2015) Relation of risk of atrial fibrillation with systolic blood pressure response during exercise stress testing. (From the Henry Ford Exercise Testing Project). Am J Cardiol 116(2): 1858-1862.

38. Irving JB, Bruce RA (1997) Exertional hypotension and post-exertional ventricular fibrillation in stress testing. Am J Cardiol 39(6): 849-851.

39. Balady GJ, Morise AP (2019) Exercise electrocardiography testing. In: Zipes DP, Libby P, et al. (Eds.), Braunwald's Heart Disease. Elsevier, Philadelphia, pp: 154-173.

40. Menghini F, Dally L, Fazzini PF (1995) The normal behaviour of circulatory parameters during exercise. Reference values for heart rate and systemic blood pressure. The ECCIS Project data. G Ital Cardiol 25(8): 967-975.

41. Gupta MP, Polena S, Coplan N (2007) Prognostic significance of systolic blood pressure increases in men during exercise stress testing. Am J Cardiol 100: 1609-1613.

42. Nauthton J, Dorn J, Oberman A (2003) Maximal exercise systolic pressure, exercise training and mortality in myocardial infarction patients. Am J Cardiol 85(3): 416-420.

43. Logan GA, Bruce RA (1958) Atypical pressor response to upright posture and exercise in patients with mitral or aortic stenosis. Am J Med Sci 236(2): 168-174.

44. Barlow PA, Olshal P, Schultz MG (2014) Low exercise blood pressure and risk of cardiovascular events and all-cause mortality: systematic review and meta-analysis. Atherosclerosis 237: 13-22.

45. American Thoracic Society (2003) American College of chest physicians ATS/ACCP statement on cardiopulmonary exercise testing. Am J Respir Crit Care Med 167(2): 211-277.

46. Le VV, Mitiku T, Sungar G (2008) The blood pressure response to dynamic exercise testing : a systematic review. Prog Cardiovasc Dis 51: 135-160.

47. Kim D, Ha JW (2016) Hypertensive response to exercise: mechanisms and clinical implication. Clin Hypertension 22: 17-20.

48. Ren JF, Hakkai AH, Kotler MN (1958) Exercise systolic blood pressure: a powerful determinant of increased left ventricular mass in patients with hypertension. J Am Coll Cardiol 5(5): 1224-1231.

49. Filipovsky J, Ducimetiere P, Safar ME (1992) Prognostic significance of exercise blood pressure and heart rate in middle-aged men. Hypertension 20(3): 333-339.

50. Morrow K, Morris CK, Froelicher VF (1993) Prediction of cardiovascular death in men undergoing noninvasive evaluation for coronary artery disease. Ann Intern Med 118(9): 689-695.

51. Lauer MS, Levy D, Anderson KM (1992) Is there a relationship between exercise systolic blood pressure response and left ventricular mass: The Framingham Heart Study. Ann Intern Med 116(3): 203-210.

52. Allison TG, Cordeira MA, Miller TD (1999) Prognostic significance of exercise induces systemic hypertension in healthy subjects. Am J Cardiol 83(3): 371-375.

53. Shim CY, Ha JW, Park S (2008) Exaggerated blood pressure to exercise is associated with an augmented rise of angiotensin II during exercise. J Am Coll Cardiol 52(4): 287-292.

54. Kuri S, Laukkanen J, Rauramaa R (32) Systolic blood pressure response to exercise stress test and risk of stroke. Stroke 32: 2036-2047.

55. Gottadiener JS, Brown J, Zoltick J (1990) Left ventricular hypertrophy in men with normal blood pressure: relation to exaggerated blood pressure response to exercise. Ann Intern Med 112: 161-166.

56. Jae SY, Fernhall B, Heffernan KS (2006) Exaggerated blood pressure response to exercise is associated with carotid atherosclerosis in apparently healthy men. J Hypertens 24(5): 881-887.

57. Chang HJ, Chung J, Choi SY (2004) Endothelial dysfunction in patients with exaggerated blood pressure response during a treadmill test. Clin Cardiol 27(7): 421-425.

58. Stewart KJ, Sunj J, Silber HA (2004) Exaggerated exercise blood pressure is related to impaired endothelial vasodilator function. Am J hypertens 17: 314-320.

59. Warner JG, Metzger DC, Kitzman JW (1999) Losartan improves exercise tolerance in patients with diastolic dysfunction and hypertensive response to exercise. J Am Coll Cardiol 33: 1567-1572.

60. Chang HJ, Chung JH, Choi BJ (2003) Endothelial dysfunction and alteration of nitric oxide /cyclic GMP pathway in patients with exercise-induced hypertension. Yonser Med J 44(6): 1014-1020.

61. Jae SY, Fernhall B, Lee M (2006) Exaggerated blood pressure response to exercise is associated with inflammatory markers. J Cardiopulm Rchabil 26: 145-149.

62. Saitoh M, Miyakada H, Kitamura H (1992) Cardiovascular and sympathetic nervous response to dynamic exercise in patients with essential hypertension. Intern Med 31(5): 606-610.

63. Lim PO, Donnan PT, Mc Donald TM (2001) Blood pressure determinants of left ventricular wall thickness mass index in hypertension comparing office, ambulatory and exercise blood pressure. J Hum Hypertens 151: 627-633.

64. Erikssen G, Bodegard J, Bjarnholt JV (2004) Exercise testing in healthy men in a new perspective: from diagnosis to prognosis. Eur Heaart J 25: 978-986.

65. Kokkinas P, Pittaras A, Narayan P, (2007) Exercise capacity and blood pressure association with left ventricular mass in prehypertensive individuals. Hypertension 49: 55-61.

66. Schultz MG, Otahal P, Cleland UJ (2013) Exercise-induced hypertension, cardiovascular events and mortality in patients undergoing exercise stress testing: a systematic review and meta-analysis. Am J Hypertens 26: 357-366.

67. Jetto M, Landry F, Blumoher G (1987) Exercise hypertension in healthy normotensive subjects: implications, evaluation and interpretation. Herz 12(2): 110-118.

68. Ellested MH (1989) Reliability of blood pressure recording. Am J Cardiol 63(13): 983-985.

69. Schultz MG, Hare JL, Marwick TH (2011) Masked hypertension is unmasked by low-intensity exercise blood pressure. Blood Press 20(5): 284-289.

70. Jackson AS, Squires WG, Grimes G (1983) Prediction of future resting hypertension from exercise blood pressure. J Cardiac Rehab 106: 316-320.

71. Monolio TA, Bruke GL, Savage PJ, Sidney S, Gardin JM, et al. (1994) Exercise blood pressure response and 5-year risk of elevated blood pressure in a cohort of young adults: The CARDIA study. Am J Hypertens 7(3): 234-241.

72. Dlin RA, Haane N, Silverberg DS, Bar-Or O (1983) Follow up of normotensive men with exaggerated blood pressure response to exercise. Am Heart J 106(2): 316-320.

73. Chaney RH, Eyman RK (1988) Blood pressure at rest and during maximal dynamic and isometric exercise as predictors of systemic hypertension. Am J Cardiol 62(16): 1058-1061.

74. Nakashima M, Miura K, Kido T, Saeki K, Tamura N, et al. (2004) Exercise blood pressure in young adults as a predictor of future blood pressure: a 12 year follow up of medical school graduates. J Hum Hypertens 18(11): 815-821.

75. Miyai N (2002) Clinical utility of exaggerated blood pressure response to exercise in evaluating the risk of future hypertension in normotensive adults. Doscentie Sports Science 23: 134-146.

76. Franz IW (1987) Exercise hypertension: its measurement and evaluation. Herz 12(2): 99-109.

77. Wilson MF, Sungh BH, Pincomb GA, Lovallo WR (1990) Exaggerated pressure response to exercise in men at risk for systemic hypertension. Am J Cardiol 66(7): 731-736.

78. Miyai N, Arita M, Morioka I, Miyashita K, Nishio I, et al. (2000) Exercise BP response in subjects with high-normal BP: exaggerated blood pressure response to exercise and risk of future hypertension in subjects with high normal blood pressure. J Am Coll Cardiol 36(5): 1626-1631.

79. Biake GA, Levin SR, Koyal SN (1990) Exercise-induced hypertension in normotensive patients with NIDDM. Diabetes Care 13(7): 799-801.

80. Sung J, Ouyang P, Silber HA, Bacher AC, Turner KL, et al.

(2003) Exercise blood pressure response is related to left ventricular mass. J Hum Hypertens 17(5): 333-338.

81. Sharman JE, Hare JL, Thomas S, Davies JE, Leano R et al. (2011) Association of masked hypertension and left ventricular remodelling with the hypertensive response to exercise. Am J Hypertens 24(8): 898-903.

82. Fagard R, Stassen J, Thijs L, Amery A (1991) Prognostic significance of exercise versus resting blood pressure in hypertension men 17(4): 574-578.

83. Shim CY, Hong GR, Park S, Yang WI, Choi D et al. (2015) Impact of central hemodynamics on left ventricular function in individuals with exaggerated blood pressure response to exercise. J Hypertens 33(3): 612-620.

84. Takamura T, Onshi K, Sugimoto T, Kurita T, Fujimoto N, et al. (2008) Patients with a hypertensive response to exercise have impaired left ventricular diastolic functions. Hypertens Res 31(2): 257-263.

85. Tsiofis C, Chatzis D, Tsiachris D, Katsi V, Toutouzas K, et al. (2008) Exaggerated exercise blood pressure response is related to tissue Doppler imaging estimated diastolic dysfunction in the early stages of hypertension. J Am Soc Hypertens 2(3): 158-164.

86. Mottram PM, Haluska B, Yuda S, Leano R, Marwick TH (2004)) Patients with a hypertensive response to exercise have impaired systolic functions without diastolic dysfunction or left ventricular hypertrophy. J Am Coll Cardiol 43(5): 848-853.

87. Weiss SA, Blumenthal RS, Sharrett AR, Redberg RF, Mora S (2010) Exercise blood pressure and future cardiovascular death in asymptomatic individuals. Circulation 121(19): 2109-2116.

88. Filipovsky J, Ducimetiere P, Safar ME (1992) Prognostic significance of exercise blood pressure and heart rate in middle-aged men. Hypertension 20(3): 333-339.

89. Lauer MS, Pashkow FJ, Harvey SA, Marwick TH, Thomas JD (1995) Angiographic and prognostic implications of an exaggerated exercise systolic blood pressure response and resting systolic blood pressure in adults undergoing evaluation for suspected coronary artery disease. J Am Coll Cardiol 26(7): 1630-1636.

90. Fagard RH, Paradaens K, Staessen JA, Thijs L (1996) Prognostic value of invasive hemodynamic measurement at rest and during exercise in hypertensive men. Hypertension 28(1): 31-36.

91. Campbell L, Marwick TH, Pashkow FJ (1999) The usefulness of an exaggerated systolic blood pressure response to exercise in predicting myocardial perfusion defects in known or suspected coronary artery disease. Am J Cardiol 84(11): 1304-1310.

92. Farmitano LD, Goday MF (2006) Increased rate pressure product as a predictor for the absence of significant obstructive artery disease in patients with positive exercise tests. Arq Bras Cardiol 86(2): 138-144.

93. Hedberg P, Ohruik J, Lonnberg I, Nilsson G (2009) Augmented blood pressure response to exercise is associated with improved long-term survival in older people. Heart 95(13): 1072-1078.

94. Smith RG, Rubin SA, Ellestad MH (2009) Exercise hypertension: an adverse prognosis. J Am Soc Hypertens 3(6): 366-373.

95. Abe K, Tsuda M, Hayashi H (1995) Diagnostic usefulness of postexercise blood pressure response for detection of coronary artery disease in patients with electrocardiographic left ventricular hypertrophy. Am J Cardiol 76(12): 892-895.

96. Tsioufis C, Dimitraids K, Thomopoulos C (2008) Exercise blood pressure response, albuminuria and arterial stiffness in hypertension. Am J Med 121(10): 894-902.

97. Taylor AJ, Betler GA (1995) Postexercise systolic blood pressure response: association with the presence and extent of perfusion abnormalities on thallium 201 scintigraphy. Am Heart J 129: 227-234.

98. Mc Ham SA, Marwick TH, Pashkow FJ (1999) Delayed systolic blood pressure recovery after graded exercise: an independent correlate of angiographic coronary disease. J Am Coll Cardiol 34(3): 754-759.

99. Tsuda M, Hatano K, Hayashi H (1993) Diagnostic value of postexercise systolic blood pressure response for detecting coronary artery disease in patients with or without hypertension. Am Heart J 125(3): 718-725.

100. Huang CL, Su TC, Chen WJ (2008) The usefulness of paradoxical systolic blood pressure increase after exercise as a predictor of cardiovascular mortality. Am J Cardiol 102(5): 518-523.

101. Laukkanen JA, Kuri S, Salonen R (2004) Systolic blood pressure during recovery from exercise and the risk of acute myocardial infarction in middle-aged men. Hypertension 44(6): 820-825.

102. Yosefy C, Jafari J, Klaiman E (2006) The prognostic value of postexercise blood pressure reduction in patients with hypertensive response during the exercise stress test. Int J Cardiol 111(3): 352-357.

103. Yamada K, Hirai M, Abe K, Ishihara H, Takeshita K, et al. (2004) Diagnostic usefulness of postexercise systolic blood pressure response for detection of coronary artery disease in patients with echocardiographic left ventricular hypertrophy. Can J Cardiol 20(7): 705-711.

104. Davidoff R, Schamroth CL, Goldman AP, T H Diamond, A J Cilliers, et al. (1982) Postexercise blood pressure as a predictor of hypertension. Aviat Space Environ Med 53(6): 591-594.

105. Hashimoto M, Okamoto M, Yamagata T, T Yamane, M Watanabe, et al. (1993) Abnormal systolic blood pressure response during exercise recovery in patients with angina pectoris. J Am Coll Cardiol 22(3): 659-664.

106. Arai Y, Saul JP, Albrecht P, L H Hartley, L S Lilly, et al. (1989) Modulation of cardiac autonomic activity during and immediately after exercise. Am J Physiol 256(1-2): H132-H141.

107. Rozanski A. Elkayam U, Berman DS, G A Diamond, J Prause, et al. (1983) Improvement of resting myocardial asynergy with cessation of upright bicycle exercise. Circulation 67(3): 529-535.

108. Miyahara T, Yokota M, Iwase M, M Watanabe, T Matsunami, et al. (1990) Mechanism of abnormal post-exercise systolic blood pressure response and its diagnostic value in patients with coronary artery disease. Am Heart J; 120(1): 40-49.

109. Kitaoka H, Tokata J, Furuno T, F Yamasaki, T Chikamori, et al. (1997) Delayed recovery of post-exercise blood pressure in patients with chronic heart failure. Am J Cardiol 71(12): 1701-1704.

110. Hambrecht R, Wolf A, Giclen S, A Linke, J Hofer, et al. (2000) Effect of exercise on coronary endothelial function in patients with coronary artery disease. N Eng J Med 342(7): 454-460.

111. Aman K, Crawford M, Petra M, O Rourke R (1983) Value of post-exercise systolic blood pressure in diagnosing coronary disease. Circulation 6: 36.

112. Ellis K, Pothier CE, Blackstone EH (2004) Is systolic blood pressure recovery after exercise a predictor of mortality? Am Heart J 147(2): 287-292.

113. Tanji JL, Champlin JJ, Wong GY (1989) Blood pressure recovery curves after submaximal exercise: a predictor of hypertension at ten years follow up. Am J Hypertens 2: 135-138.